AD 674656

AD

68-1865

TRANSPARENT ARMOR: A LITERATURE SURVEY

TECHNICAL REPORT

By

Robert E. Ofner

July 1968

SCIENCE & TECHNOLOGY LABORATORY

RESEARCH & ENGINEERING DIRECTORATE

U. S. ARMY WEAPONS COMMAND

This document has been approved for public release and sale;
its distribution is unlimited.

Reproduced by the
CLEARINGHOUSE
for Federal Scientific & Technical
Information Springfield Va 22151

23

AD

SCIENCE & TECHNOLOGY LABORATORY

RESEARCH & ENGINEERING DIRECTORATE

U. S. ARMY WEAPONS COMMAND

TECHNICAL REPORT

68-1865

TRANSPARENT ARMOR: A LITERATURE SURVEY

By

Robert E. Ofner

July 1968

DA No. 1G024401A105 AMS Code 5025.11.26800.04

This document has been approved for public release and sale; its distribution is unlimited.

ABSTRACT

One hundred and thirty three references to published work pertaining to transparent armor for use in the vision ports of Army ground vehicles or in aircraft enclosures are listed under ten categories, as follows: state of the art; glass; plastics; glass-plastic; single crystal ceramics; dynamic properties of polymers; fiber optics; vision blocks; military specifications, handbooks and drawings; bibliographies.

CONTENTS

OBJECTIVE

To survey the literature on transparent armor and to prepare a bibliography of those publications which best describe important achievements of past years, the current state of the art and the most promising approaches to the development of minimum weight armor having an optimum balance between optical clarity and resistance to projectiles.

BACKGROUND

The combat effectiveness of Army land and air borne vehicles is largely dependent upon the ability of the crews to perform the visual observations required by their missions, without undue danger from enemy gun fire. Any material which provides both the required visibility and the ballistic protection is termed "transparent armor".

Army needs for transparent armor are largely limited to two types of applications, the enclosures of aircraft and the vision ports of ground vehicles. Enclosures are canopies, windows or windshields while vision ports are best exemplified by the glass blocks in the cupulas of armored vehicles. Another class of item usually associated with transparent armor is the sighting device, such as the periscope, telescope or range finder. Here, of course, emphasis is placed on the need for unimpaired vision, with ballistic protection as a secondary requirement.

Transparent armor, combining optimum visibility and resistance to projectile penetration, has been an exceedingly difficult item to develop, largely because of the inherent incompatibility of these properties in available materials. Until shortly after World War II, transparent armor usually consisted of "safety" or "bullet proof" glass, two or more panels of glass laminated with a thin, flexible plastic interlayer. Although glass has the best optical properties of all known materials, it is brittle and has little tendency to defeat projectiles unless it is used in thicknesses so large that vision is impaired and the weight and volume of the armor become unacceptable.

The post war era brought forth a proliferation of new, commercially available plastics and elastomers, several with good optical clarity and some with excellent resistance to impact and projectile penetration. A large amount of research was initiated to make use of these new polymers in glass-plastic composite armor or in all-plastic laminated armor. The use of the new, transparent rubbers as interlayers was also investigated. These efforts are continuing today and significant reductions in the weight of "bullet proof" glass have been achieved without loss of ballistic protection.

The influx of plastics and rubbers into a field heretofore served primarily by glass, stimulated a large effort by major glass manufacturers to improve their product. Stronger, higher moduli glasses with improved clarity and better resistance to aging have resulted. Fiber optics may be of value here. This research effort is also continuing.

In about 1963, the U. S. Army Natick Laboratories, in conjunction with the Army Materials Research Agency (now the Army Materials and Mechanics Research Center), initiated efforts with industry toward the development of single crystal ceramics. Details of this work are classified but the "synthetic sapphire" holds much promise for the future of lightweight transparent armor.

The many polymers synthesized in recent years have prompted the development of new analytical tools and techniques for determining their properties. A vast amount of research involving these analytical methods is currently in progress to investigate the photoelastic properties of polymers, to conduct dynamic stress analyses on polymers as a function of their structure. A more fundamental understanding of these properties and responses of materials is necessary to insure continued advances in the development of lightweight, transparent armor.

This survey was prepared for use by the Army designer of transparent armor, with the hope that by examining judicious selections from the referenced reports and papers, he might become familiar with the state of the art and with the anticipated developments of the future, thereby increasing his capability to provide the Army with the best transparent armor available.

Future Efforts by the Army Weapons Command (AWC)

Bearing in mind that AWC's primary interest in transparent armor lies with vision blocks and fire control sighting devices, three approaches appear to be applicable to the future improvement of these items, namely, the improvement of the all-polymeric (plastic or plastic-rubber) armor: the development of single crystal ceramic armor and the use of fiber optics.

Although plastic armor has already been developed with improved ballistic protection over that obtainable with the same weight and thickness of safety glass, much work remains to be done. New, commercially available rubbers and plastics need to be evaluated as anti-spall materials and as interlayers; improved resistance to aging, discoloration and scratching is needed in the polymeric composite armor; improved resistance to temperature extremes is required and composite armor made of materials having like coefficients of thermal expansion is required. Program funding in these areas of endeavor should be considered by AWC.

Single crystal ceramics are currently under development through the joint efforts of the Army Natick Laboratories, the Army Materials and Mechanics Research Center and private industry. This work should be monitored closely by AWC in order that the knowledge required to use these ceramic materials in armor might be available at such time as they become economically competitive with more conventional materials. The cost of fabricating the single crystal materials is exorbitant at this time.

The techniques of fiber optics need to be investigated, especially in relation to sighting devices. Fiber optics may provide novel methods of obtaining external visibility from the interior of armored vehicle. Funding of programs in this area is recommended.

Sources for the Bibliography

No bibliography on transparent armor was known to the author at the onset of this survey. Accordingly, a "Report Bibliography on Transparent Armor" was requested from the Defense Documentation Center (DDC). Thirty seven of the fifty military reports abstracted in the DDC bibliography were applicable to transparent armor and were obtained from DDC. Many of these reports contained references to other reports, books and published articles, including a few bibliographies on armor. These were obtained whenever possible or the references were listed when applicable. No open literature was surveyed because the majority of publications on transparent armor are classified. Mr. A. Alesi of the Natick Laboratories and Mr. G. Parsons of Army Materials and Mechanics Research Center were helpful in furnishing references to military reports.

BIBLIOGRAPHY

State of the Art

The most comprehensive of the seven reports referenced below is ABI-88. It includes the anticipated usage and requirements for transparent armor, summarizes present and future costs and presents a planned five year development program.

"N Labs Report on Armor Materials Research" (U), U. S. Army Natick Laboratories, April 1964, Confidential, AD350785.

"A Review of Vision Devices for Combat Vehicles" (U), D. W. Rees, U. S. Army Tank Automotive Center, Technical Report No. 8889, 4 June 1965, Confidential, AD368875.

"State-of-the-Art Study on Armor Materials Applicable to Modular Construction" (U), J. F. Shea, et al, Battelle Memorial Institute, October 1965, Secret, AD36690.

"Proceedings of the Second Symposium on Lightweight Armor Materials" (U), Held at Pittsburgh, Pennsylvania, 5-6 May 1966, Army Materials Research Agency, Monograph Series, MS 66-07, Vol I, October 1966, Secret.

"Transparent Armor Materials Technology" (U), U. S. Army Natick Laboratories and U. S. Army Materials Research Agency, ABI-88 (Special), 14 June 1967, Secret.

"Presentation on Armor Materials for Protection Against Small Arms Ammunition" (U), Presented at the Armor and Armor Penetration Conference, Frankford Arsenal, 22-23 August 1967, Secret.

"Light Armor Materials" (U), Technical Information Report, AMC Control (S), 9968-67, October 1967, Secret.

Glass

Studies which are predominatly concerned with the use of glass as an armor material are referenced here. The older studies are included because they establish concepts important to the development of glass armor.

"On Shooting Through Glass with a Rifle", F. W. Preston, J. Soc. Glass Tech. 11, 283, 1927.

"The Surface Strength of Glass and Other Materials", F. W. Preston, J. Soc. Glass Tech. 17, 5, 1933.

"Modulus of Rupture and Thermal Shock Resistance at Elevated Temperatures". J. S. Aregorius, Bull. Am. Ceram. Soc. 15, 271-3 (1936).

"Strength of Glass Fiber", F. O. Anderegg, Ind. Eng. Chem. 31, 290, 1939.

"Summary of Previous Reports: Bullet-Resisting Glass, Flexseal Laminated Glass, Bent Glass", Technical Glass Bulletin No. 1, Pittsburgh Plate Glass Co., April 1941.

"Further Study of Glass Fracture with High-Speed Photography", H. E. Edgerton and F. E. Barstow, J. Am. Ceramic Soc. 24, 131, 1941.

"Mechanical Properties of Glass", F. W. Preston, J. Applied Phys. 13, 623-34 (1942).

"The Strength of Glass Fibers", J. B. Murgatroyd, J. Soc. Glass Tech. 28, 358, 1944, and 28, 383, 1944.

"The Light Armor Testing Laboratory and Research Relating Thereto", Contract No. W-44-109-qm-305, Final Report, Monsanto Chemical Co., 1945.

"The Mechanical Strength of Glass", W. A. Wehl, Glass Ind. 27, 17, 1946.

"Strength of Plastic and Glass", M. Harris, Inter-Science Publishers, 1949.

"Glass as an Engineering Material", K. Rose, Materials and Methods, March 1951.

"Strength of Glass", G. Slayter, Ceramics Bull. 3[illegible] 276, 1952.

"Analysis of Some Experimental Data on Glass as a Tank Armor to Defeat Shaped Charges" (U), Ballistic Research Laboratories Report No. 643, February 1953. Confidential.

"Some Experiments on Composite Armor Using Glass to Defeat Shaped Charges" (U), Ballistic Research Laboratories Memorandum Report No. 712, August 1953. Confidential.

"Temperature Dependence of the Plastic Moduli and Internal Friction of Silica and Glass", J. W. Marx and J. M. Sivertsen, J. Appl. Phys. 24, 81, 1953.

"A Note on the Structure of Glass Fiber", S. Bateson, J. Soc. Glass Tech. 37 302, 1953.

"Elastic Moduli o Glasses by a Dynamic Method", S. Spinner, J. Am. Ceram. Soc. 37, 229-34, (1954).

"Optical Studies of Ring Cracks of Glass", S. Tolansky and V. R. Howes, Proc. Phys. Soc. Lond. 67B, 467, 1954.

"Properties of Glass", G. W. Morey, 2nd Edition, 1954, Reinhold Publishing Corporation.

"Lithium Development and Expansion", H. E. Simpson, Glass Industry, 36, 17, 1955.

"Some Physical Factors Affecting the Internal Damping of Glass", S. L. Bluhm, J. Am. Ceram. Soc. 38, 205, 1955.

"Ceramics as Basic Engineering Materials", E. J. Smoke and J. H. Koenig, Mech. Eng, April 1956, p. 315.

"Eye Protection Against Small High-Speed Missiles", H. W. Rose and G. M. Stewart, School of Aviation Medicine, U. S. Air Force Randolph Air Force Base, 1956.

"A Method of Reducing Behind the Armor Damage Resulting from a Shaped Charge Perforation", The Ordnance Corps Shaped Charge Research Report No. 3-57, July 1957.

"Development of a Bonded Edge Attachment Which Allows the Use of Plate Glass as a Structural Element in Aircraft Canopies", WADC Technical Report 57-768, November 1957. AD142345.

"Glass Engineering Handbook", E. B. Shand, McGraw Hill Publishing Corporation, 1958.

"Ballistic Evaluation Tests of Heat Tempered Laminated Glass" (U), D. T. Gray, U. S. Naval Weapons Laboratory, 29 June 1960, Confidential, AD315953.

"Glass, Its Industrial Applications", Reinhold Publishing Corporation, 1960.

"Armor and its Application to Vehicles" (U), Ordnance Engineering Design Handbook ORDP 20-170, December 1961, Confidential.

"High Temperature Aircraft Windshield Development Program", ASD Technical Report 62-7-654, Vols I and II, June 1958 and May 1962.

"Research in High Temperature Window Design", ASD Technical Report 61-356, June 1962.

"Properties of Glasses at Elevated Temperatures", WADC Technical Report 5-645, Parts I thru VIII, May 1957 to March 1963.

"Research in Extreme Environment Aerospace Vehicle Window Assemblies", Contract No. AF33(616)8226, Narmco Research and Development for Air Force Systems Command, ASD-TDR-62-570, April 1963.

"Borosilicate Glasses", Materials and Process Manual No. 220, Materials in Design Engineering, June 1964.

"Development of Reinforced Transparent Armor (Aircraft Armor)" (U), Contract No. DA19-129-AMC-358(N), Illinois Institute of Technology Research Institute for U. S. Army Natick Laboratories, April 1965, Confidential.

"Ballistic Evaluation of Some Exploratory Transparent Armor Systems", Contract No. DA-19-129-AMC-435(N) Corning Glass Works for U. S. Army Natick Laboratories, August 1965.

"Transparent Armor" (U), Contract No. DA-36-034-AMC-0309X, Pittsburgh Plate Glass Co. for U. S. Army Materials Research Agency, Final Report, August 1965, Confidential AD375935.

"Ballistic Evaluation of Some Exploratory Transparent Armor Systems" (U), Contract No. DA-19-129-AMC-435(N), Corning Glass Works for U. S. Army Natick Laboratories, August 1965, Confidential.

"Glass Parts: How to Select and Specify", Materials and Processes Manual No. 243, Materials Engineering, August 1967.

Plastics

Included here are references to the use of plastics in armor, either as the predominant material or as the inter-layer for glass armor.

"The Formation and Enlargement of a Circular Hole in a Thin Plastic Sheet", G. I. Taylor, Quarterly J. Mech. and Appl. Math 1, 103, 1948.

"The Work to Create Fracture Surfaces in Polymethyl Methacrylate", M. Bowman and H. L. Smith, Paper presented at the New York Meeting of the Am. Phys. Soc. on February 2, 1952.

"Gunfire Tests on Transparent Panels", C. J. Cardona, June 1953, WADC Technical Report 53-375. AD38143.

"Estimations of Ballistic Penetration of a Soft Projectile into Massive Plastic", F. T. Rogers, Technical Note 11-54-P4 of Dept. of Physics, Univ. of South Carolina. 1954.

"The Investigation of Multiaxially Stretched Acrylic Plastic", J. Gouza and D. A. Hurst, Watertown Arsenal Technical Report 54-619, 1954.

"The Formation of a Conical Crater in a Thin Plastic Sheet", W. T. Thomson, J. Applied Mech. 22, 175, 1955.

"Resistance to Shattering by Gunfire of Transparent Laminated Materials for Aircraft Glazing", E. M. Petruska, WADC Technical Report 56-133, August 1956, AD97191.

"Ballistic Properties of Plastic Laminates and Aluminum Alloy" (U), Wright Air Development Center Report 56-484, Part I, 1956, Confidential.

"Development of Personnel Armor", National Bureau of Standards Report No. 4671, 1956.

"Silicone Interlayer Material Program", Contract No. AF33(600)-27183, Dow Corning Corporation for Wright Air Development Center, July 1957, WADC Technical Report 57-213, AD130887.

"Some Ballistic Properties of CR-39 Plates", E. S. Emerson, Presentation given at Quartermaster Research and Engineering Center Symposium, Sept 19 1957, Natick, Mass.

"Composite Personnel Armor", A. L. Alesi, Quartermaster Research and Engineering Command, Report CP-5, December 1957.

"Silicone Interlayer Program", Part II Contract No. AF33(600)-34984, Dow Corning Corporation for Wright Air Development Center, August 1958, WADC Technical Report 57-213, AD155803.

"Ballistic Test of Plastic Vision Blocks" (U), Aberdeen Proving Ground Report No. DPS/OTAC-R/1, W. T. Pibil, April 1959, Confidential, AD306591.

"Development of a Structural Organic Bonded Edge Attachment for Inner Panels of Double Glazed Windshield and Canopy Units", J. W. Mahoney, North American Aviation, Inc., Report 60-352, March 1960.

"A Method of Suppressing Small Fragments" (U), Ballistic Research Laboratories Memorandum Report No. 1370, S. Kronman, September 1961, Confidential, AD327219.

"The Resistance of Various Non-Metallic Materials to Perforation by Steel Fragments; Empirical Relationships for Fragment Residual Velocity and Residual Weight" (U), Contract No. DA-36-034-ORD-29RD The Johns Hopkins University for Ballistic Research Laboratories, Technical Report No. 51, April 1963, Confidential, AD336461.

"Current Technology of Light Armor Materials for U. S. Army Aircraft (U), U. S. Army Materials Research Agency Monograph Series, AMRA MS 63-03, E. N. Hegge and M. F. Medeiros, May 1963, Confidential, AD354270.

"Engineer Design Test of Plexiglas II Transparent Plastic (Ballistic Evaluation)" (U), Aberdeen Proving Ground Report DPS-959, R. J. Vancaneghem, June 1963, Confidential, AD337090.

"Reduction of Army Aircraft Vulnerability" (U), Ballistic Research Laboratories Memorandum Report No. 1496, p. 29, J. J. Dailey, et al, August 1963 Confidential, AD345047.

"Ballistic Technology of Lightweight Armor Materials" (U), U. S. Army Materials Research Agency Monograph Series, AMRA MS 64-07, F. S. Mascianica, September 1964, Confidential, AD354074.

"Proceedings of Symposium on Lightweight Armor Materials" (U), U. S. Army Materials Research Agency Monograph Series AMRA MS 65-01, March 1965, Secret.

"Ceramic Composite Armors" (U), U. S. Army Materials Research Agency AMRA TR 65-13, June 1965, Secret.

"Study of Dynamic Birefringence and Strain Produced in Transparent Polymers by Mechanical Impact", A. F. Wilde et al, U. S. Army Natick Laboratories, February 1966 AD630913.

"Feasibility of Armor Materials as Basic Aircraft Structure", Contract No. DA-44-177-AMC-189(T), North American Aviation, Inc. for U. S. Army Aviation Materiel Laboratories, Report 66-5, March 1966, AD631467.

"Development of Reinforced Transparent Armor (Aircraft Armor, Transparent, Reinforced)" (U), Contract No. DA19-129-AMC-358(N), Illinois Institute of Technology Research Institute for U. S. Army Natick Laboratories, April 1966, Confidential, AD374215.

"Ballistic Behavior of Ceramic Composite Armor" (U), U. S. Army Materials Research Agency, C. W. Semple, 11 June 1966, Secret, AD374334.

"Proceedings of the Second Symposium on Lightweight Armor Materials" (U), Held at Pittsburgh, Pennsylvania, 5-6 May 1966, Army Materials Research Agency Monograph Series, MS 66-07, Vol II, October 1966, Secret, AD378973.

"Study of Hot Stretching of Transparent Plastics", Contract No. DA19-129-AMC-844(N), Lowell Technological Institute Research Foundation for U. S. Army Natick Laboratories, November 1967.

Glass-Plastic

Studies which deal with both glass and plastic as individual armor materials, or which deal with the use of both materials in composite structure, are referenced here.

"Temperature Limitations of Polymeric Materials", Royal Aircraft Establishment Technical Note No. CPM 53, April 1964, Clearinghouse for Federal Scientific and Technical Information Accession N67-22782.

"Proceedings of Symposium on Lightweight Armor Materials" (U), U. S. Army Materials Research Agency, MS 65-01, March 1965, Secret.

"Transparent Materials for Aerospace Enclosures", Air Force Materials Laboratory Conference, Dayton, Ohio, 8-10 December 1964, AFML Technical Report 65-212, September 1965, AD473543.

"Transparent Composite Armor Materials for Aircraft Applications" (U), Contract No. DA-04-495-AMC-328(Z), Aerojet-General Corporation for U. S. Army Natick Laboratories, Technical Report 67-6-CM (Final Report), July 1966, Confidential, AD376983.

"Information for Selection of Lightweight Armor Materials for Aircraft" (U), Contract No. AF33(615)-3331, Goodyear Aerospace Corporation for Air Force Materials Laboratory, September 1966, Secret, AD376262.

"Development of Transparent Armor System for Aircraft" (U), Contract No. DA-19-129-AMC-742(N), Swedlow, Inc. for U.S. Army Natick Laboratories, Technical Report 67-44-CM, December 1966, Confidential, AD380442.

"The Effect of Nylon Glass Arrangements in Defense Against Shaped Charge Ammunition" (U), Ballistic Research Laboratories Shaped Charge Research Report No. 3-57, July 1957, Confidential.

"Transparent Materials for Aircraft Enclosures, WADC University of Dayton Joint Conference", Wright Air Development Center TR57-421, October 1957, AD142021.

"Transparent Ceramic Composite Armor" Patent Application submitted by U. S. Army Materials Research Agency, AMC Docket Nr. 3476.

Single Crystal Ceramics

These reports cover the recently developed "synthetic sapphires". Other discussions on this subject may be found in the state of the art reports.

"Ceramic Composite Armors" (U), C. W. Semple, U. S. Army Materials Research Agency Technical Report 65-26, October 1965, Secret.

"A Comparison of the Impact Behavior in Composites of Single Crystal and Polycrystalline Ceramics" (U), A. L. Alesi, M. I. Kliman and G. R. Thomas, U. S. Army Natick Laboratories, 11 June 1966, Secret, AD374336.

Dynamic Properties of Polymers

Studies which relate the structure of polymers to their ability to resist fracture are referenced here.

"Fracture and Comminution of Brittle Solids", E. Poncelet, Metals Technology 11, 1, 1944.

"Theory of Orientation and Double Refraction in Polymers" E. F. Gurnee, J. Appl. Phys. 25 1232, 1954

"The Photoelastic Properties of Short-Chain Molecular Networks", L. R. G. Treloar, Trans. Far. Soc. 50, 881, 1954.

"A Photoelastic Study of Dynamic Stresses in Structures", M. M. Frocht and P. D. Flynn, Contract No. NOy-28149, Illinois Institute of Technology for U. S. Navy, 1954.

"Propagation of Elastic Impact in Beams in Bending", M. Goland, J. Appl. Mech., March 1955.

"Studies in Dynamics Photoelasticity", M. M. Frocht and P. D. Flynn, J. Appl. Mech. 23, 116, 1956.

"Application of High-Speed Photography to Dynamic Stress Analysis", D. G. Christie, From the book "Photographie et Cinematographie Ultra-Rapides", Dunod, Paris, 1956.

"The Study of the Propagation of Stress Waves by Photoelasticity", J. C. Feder et al, Proc. SESA, 14, 109, 1956.

"Applicability of Dynamic Photoelastic Analysis to the Study of Impact Phenomena", E. S. Emerson, Presentation given at Quartermaster Research and Engineering Center Symposium, Sept 16, 1957, Natick, Mass.

"Dynamic Photoelasticity by Means of Streak Photography", M. M. Frocht, P. D. Flynn and D. Landsberg, Proc. SESA 14, No. 2, 81, 1957.

"Polyurethane Rubbers: Part 3: Further Polyesters and Polyester Polyurethanes" (U), B. L. Hollingsworth and W. H. G. Wright Explosives Research and Development Establishment, Waltham Abbey, England, 29 June 1960, Confidential AD 139020.

"Investigation of the Energy Absorption Characteristics of New Polymeric Materials" (U), E. S. Emerson and W. Shurcliff Polaroid Corporation, 29 June 1960, Confidential, AD153763.

"Study of Dynamic Birefringence and Strain Produced in Transparent Polymers by Mechanical Impact", A. F. Wilde, et al, U. S. Army Natick Laboratories, Tech. Report 66-6CM, February 1966.

"Study of Fracture as Related to Polymer Structure", Contract DAAG 17-67-C-0133, Illinois Institute of Technology for U. S. Army Natick Laboratories, December 1967.

Fiber Optics

The relatively new field of fiber optics, the transmittal of light along "bundles" or fibers of glass, is covered in this bibliography because of the potential usefulness of this technique in sighting devices and perhaps even in vision ports.

"Fiber Optics", N. S. Kapany, Scientific American, November 1960.

"Ceramic Fiber Optics" (U), Contract DA-44-099-eng-5015, Horizons Inc., Final Report, November 1964, Confidential AD377466.

"Fiber Optics Environmental Test", Contract No. DA-36-038-ORD-21165M, Nortronics, Final Report, March 1965 AD815381.

"Continuous Facsimile Scanner Employing Fiber Optics", Contract DA-28-043-AMC-00164(E). Illinois Institute of Technology Research Institute, March 1967, AD649385.

"Fiber Optics with Extended Ultraviolet Transmission", Contract DAAB07-67-C-0542, Illinois Institute of Technology Research Institute, Triannual Report No. 1, February 1968 AD665410.

Vision Blocks

The end use of transparent armor of most interest to the Army Weapons Command is that of the vision blocks in the cupula of tracked vehicles. Because of this interest, this topic is referenced separately.

"Determination of Relative Resistance to Ballistic Attack of Old Deteriorated Vision Blocks as Compared with New Vision Blocks for Commander's Cupola", Aberdeen Proving Ground Report No. AD-1155.

"A Technological Survey of Vision Block Materials Design", Contract No. DA-20-018-23389. Aerofab Company, Inc. for U. S. Army Tank Automotive Center. October 1952. AD296270.

"The Dynamics of Terminal Ballistics (Ballistic Evaluation Procedures for Armored Grille Designs)", Contract No. DA-23-072-ORD-1302, University of Denver for U. S Army Tank Automotive Center. Final Report. February 1962 AD328796.

"Research to Optimize the Ballistic Performance of Armor Vision Blocks", Vol I, Contract No. DA-23-072-ORD-1619, University of Denver for U. S. Army Tank Automotive Center, Final Report, November 1963, AD429147.

"Research to Optimize the Ballistic Performance of Armored Vision Blocks Vol. II, Ballistic Testing and Design Phase" (U), Final Report, Contract No. DA-23-072-ORD-1619, University of Denver, Denver Research Institute, 1 November 1963, Confidential, AD347155.

"Engineer Design Test of Tank, M60A1; Evaluation of Vision Block Configuration" (U), M. K. Spear, Aberdeen Proving Ground Report No. DPS-2108, August 1966, Confidential, AD375476.

"Initial Production Test of Miscellaneous Types of Vision Blocks (Ballistic Evaluation)" (U), Firing Record No. AR-27456, 9 January 1967, Aberdeen Proving Ground, Confidential.

<u>Military Specifications, Handbooks and Drawings</u>

MIL-G-174, "Glass, Optical"

MIL-G-1366, "Glass, Window, Aerial Photographic"

MIL-P-5425, "Plastic, Sheet, Acrylic, Heat Resistant"

MIL-G-5485, "Glass; Laminated, Flat, Bullet-Resistant"

MIL-D-5813, "Dome, Navigators Observing, Non-Pressurized Aircraft, Type A-3A"

MIL-P-8184, "Plastic Sheet, Acrylic, Modified"

MIL-P-8257, "Plastic Sheet, Thermosetting, Transparent"

MIL-A-8576, "Adhesive, Acrylic Base, For Acrylic Plastic"

MIL-G-8602, "Glass, Laminated, Flat, Aircraft

MIL-B-11352, "Block Vision: Bullet-Resistant"

MIL-C-18767, "Cleaning and Polishing Compound, Transparent-Plastic Aircraft Materials"

MIL-G-25667, "Glass, Monolithic, Aircraft Glazing"

MIL-P-25690, "Plastic, Sheets and Parts, Modified Acrylic Base, Monolithic, Crack Propagation Resistant"

MIL-G-25871, "Glass, Laminated, Aircraft Glazing"

Army Ordnance Corps Drawing B6285382, "Block, Direct Vision"

Army Ordnance Corps Drawing C6300790, "Block, Direct Vision"

"Plastics for Flight Vehicles" MIL-HDBK-17, Part II, "Transparent Glazing Materials", August 1961

Bibliographies

The following bibliographies on armor were discovered during the course of the literature survey. The few references to transparent armor which were found in these bibliographies have been listed under the applicable headings.

"Investigation of the Energy Absorption Characteristics of New Polymeric Materials" (U), Final Report, Contract DA 11-129-QM-209 Polaroid Corporation for Quartermaster Research and Engineering Center, 31 December 1957, Confidential, AD153763.

"Materials Briefs", Number 9, p. 13, September 1966, Air Force Materials Laboratory. AD489912.

"Current Status of Lightweight Armor Materials" (U), Contract No. SD-171, Battelle Memorial Institute for Advanced Research Projects Agency, January 1967, Secret. AD381956.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U. S. Army Weapons Command Research & Engineering Directorate Rock Island, Illinois 61201	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

TRANSPARENT ARMOR: A LITERATURE SURVEY

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Robert E. Ofner

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 1968	28	133

8a. CONTRACT OR GRANT NO. b. PROJECT NO. DA No. 1G024401A105 c. AMS Code 5025.11.26800.04 d.	9a. ORIGINATOR'S REPORT NUMBER(S) 68-1865 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Weapons Command

13. ABSTRACT

One hundred and thirty three references to published work pertaining to transparent armor for use in the vision ports of Army ground vehicles or in aircraft enclosures are listed under ten categories, as follows: state of the art: glass; plastics: glass-plastic; single crystal ceramics; dynamic properties of polymers; fiber optics; vision blocks; military specifications, handbooks and drawings, bibliographies. (U) (Author)

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE

Unclassified

Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Transparent armor						
2. Vision blocks						
3. Glass						
4. Plastics						
5. Fiber optics						

Unclassified

Security Classification

SUPPLEMENTARY

INFORMATION

AD-674 656 Army Weapons Command, Rock Island, Ill. Science and Technology Lab. Technical rept. Rept. no. RIA-68- 1865 Jul 68	No limitation	USGO: others to Army Weapons Command, Attn: STL, Rock Island, Arsenal, Ill.	USAWC notice, 11 Jun 69